END

FILMED

DTIC

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

TR-2519 ①

DAVIDSON
LABORATORY

REPORT SIT-DL-85-9-2519

WATERJET PROPULSION SYSTEM PERFORMANCE
IN A MANNED TESTCRAFT IN
CALM WATER

by

D. Lueders
and
E. Numata

STEVENS INSTITUTE
OF TECHNOLOGY

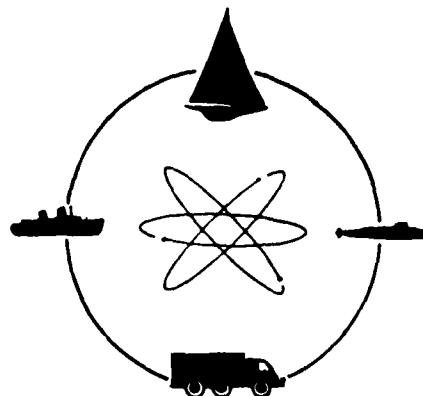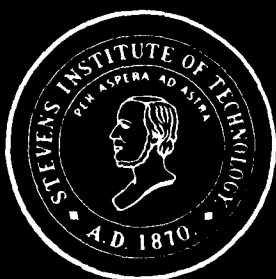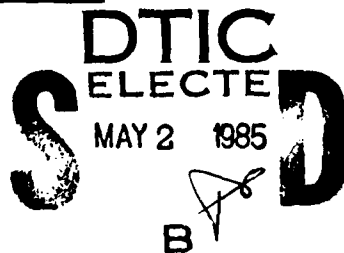CASTLE POINT STATION
HOBOKEN, NEW JERSEY 07030

DTIC
ELECTE
MAY 2 1985
B

85 04 08 031

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SIT-DL-85-9-2519	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Waterjet Propulsion System Performance in a Manned Testcraft in Calm Water.		5. TYPE OF REPORT & PERIOD COVERED FINAL July-December 1984
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) D. Lueders and E. Numata		8. CONTRACT OR GRANT NUMBER(s) N00014-83-C-0780
9. PERFORMING ORGANIZATION NAME AND ADDRESS Davidson Laboratory Stevens Institute of Technology Hoboken, New Jersey 07030		10. PROGRAM ELEMENT. PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research 800 North Quincy Arlington, VA 22217		12. REPORT DATE March 1985
		13. NUMBER OF PAGES 38
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) David W. Taylor Naval Ship Research and Development Center, Code 1120 Bethesda, MD 20034		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: Distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Waterjet Propulsion
Amphibian

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
An existing 14.5-ft manned testcraft was fitted with a fixed bow plate, fixed chine flaps, and adjustable transom flaps. Trials were conducted in a freshwater lake to evaluate the performance of its waterjet propulsion system which used a 14-in dia impeller. Propulsion shaft thrust, torque and rpm, waterjet velocity, testcraft speed and running trim were recorded for a range of rpm up to full throttle of the 330 hp gasoline engine. Zero speed "bollard pull" runs were included. Test variables included three impellers, three flush inlet sizes, and three waterjet nozzle sizes.

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73
S/N 0102-014-6601

WATERJET PROPULSION SYSTEM PERFORMANCE IN A MANNED TESTCRAFT IN CALM WATER

by

D. Lueders

and

E. Numata

Approved: *[signature]*
Daniel Savitsky
Director

TABLE OF CONTENTS

INTRODUCTION

The U.S. Marine Corps is supporting an effort to increase the efficiency of waterjet propulsion units in their amphibious vehicles. During the past two years Davidson Laboratory and John K. Roper Associates have been engaged in design, construction and evaluation trials of an axial flow pump capable of vehicle speeds up to 25 miles per hour.

Construction of a manned testcraft and its waterjet system was completed in July 1983 and a performance trial was conducted during August 1983. Reference 1 describes the testcraft and waterjet system, presents results of the trials, and identifies aspects of performance to be investigated in the next trial.

The testcraft was modified and additional instrumentation was assembled during the winter and spring of 1984. Following two preliminary trials during the spring season, final trials were conducted on 9 and 10 July 1984. This report includes a description of the modified testcraft and its waterjet propulsion system; the instrumentation and the procedures used in the trials; and a tabulation of test data. Analysis of trial results is covered in a companion report, Reference 2.

This work was performed under Office of Naval Research Contract N00014-83-C-0780. Mr. Walter Zeitfuss of the U.S. Marine Corps Program Office, Code 112 DTNSRDC, was technical monitor of the project.

TESTCRAFT AND TEST PROCEDURE

Figure 1 is a four-view sketch of the testcraft configuration for the July 1984 trial. Changes in configuration since the August 1983 trial (Reference 1) included:

- Addition of a fixed bow plate and fixed chine flaps to improve hull performance.

- Addition of controllable transom flaps to obtain optimum trim at a given engine speed.

- Removal of watertight enclosures around track wells and installation of aluminum plate bottom and side boundaries on each track well.

Appendix A contains descriptions of the testcraft and its operating equipment.

Analysis of the August 1983 trial data (Reference 1) suggested that any future trial should include instrumentation to obtain the following data:

- Jet velocity traverses should be conducted over the full range of shaft rpm.

- Bollard push should be measured by a load cell for comparison with jet thrust derived from jet velocity measurements.

To meet the first recommendation, a horizontal rack holding 16 Prandtl tubes was designed, constructed, and installed across the center of the waterjet exit. The arrangement of the tubes and the rack support frame were such as to accommodate the longitudinal location and diameter of each of two nozzles, as well as a case with no nozzle, Figure 2. A differential pressure sensor was assigned to each of the sixteen Prandtl tubes and a complete velocity distribution across the waterjet was obtained for each test run.

A mechanical-type load cell, anchored to a shoreside "bollard", was connected by steel wire cable to a chain bridle attached to the testcraft transom. Zero speed "bollard pull" tests were conducted for seven impeller-nozzle-inlet combinations, in which a visual reading of the load cell dial was compared to jet thrust derived from a Prandtl tube velocity distribution.

Testcraft speed had been measured by a radar gun during the 1983 trial, but it required two test personnel at a fixed station. One person aimed the gun and reported speed readings to a second person who had to record the readings. This process was cumbersome and it was decided to use a water velocity transducer whose output could be recorded automatically with all other measurements. A total head tube was fixed to the leading edge of the port rudder, well below the testcraft keel. Pressure change relative to a static floating zero was recorded during each forward speed run to permit calculation of testcraft velocity through the water.

Appendix B gives additional details of the above instrumentation, as well as descriptions of data recording equipment and other data sensors.

All tests were conducted on Lake Nubanusit near Hancock, New Hampshire. The clear, deep, fresh water lake, with little boat traffic on weekdays, permitted speed test runs of several hundred yards in length. The testcraft driver was able to maintain radio communication with a shore station. Paper tape printouts from the data logger were collected in the cockpit, retrieved periodically by a chase boat and brought to the shore station to be monitored. Static floating zero readings were recorded periodically, and 24 channels of data were recorded at least twice during each constant speed run.

TEST PROGRAM

Major variables in the waterjet system were:

- Three inlet opening lengths: 33, 23, 19.5 inches

- Three impeller projected area ratios: 1.0, 1.5, 2.25

- Three waterjet exit diameters: 14.12, 12.25, 10.5 inches

The matrix of the three major variables was as follows, where the numbers in the matrix spaces are impeller area ratios.

Waterjet Exit Dia. Inches	Inlet Entrance Length, inches		
	33	23	19.5
14.12	1.5** 2.25		
12.25	1.0* 1.5 2.25	1.5	1.5
10.5	1.0 1.5** 2.25		

* Bollard pull only

** Speed runs only

DATA REDUCTION

Paper tapes from the data logger listed output in the form of a digital voltage for each of 24 data channels. These data were processed as follows, using a TI Programmable 59 desk calculator with printer.

1. All voltages for each channel during one run were averaged and a calibration factor was applied to obtain an output in engineering units. Results of this step were listed directly for shaft rpm, shaft thrust, shaft torque, static pressures in the inlet duct, and testcraft trim.

2. Average dynamic pressure P_D from Step (1) for each Prandtl tube was converted to a fluid velocity

$$V = 0.96 \sqrt{2P_D/\rho}$$

where the constant 0.96 was determined by experiment. Each velocity was then input to a flow volume integration program which computed a flow rate

$$Q = \Sigma \; V \; \delta \; A$$

where δA is an annular area in the measurement plane across which V acts. This integration was performed separately for port side and for starboard side velocities, and an average of the two flow rates was then printed. A program also calculated the average waterjet velocity in the measurement plane

$$V_j = Q/A$$

where A is the area of the waterjet exit, and then the waterjet thrust

$$T_j = \rho \; Q \; (V_j - V_o)$$

where V_o is craft speed, and also the advance ratio at the impeller casing

$$J_c = (Q/A_c) \; / \; n \; D_c$$

where A_c and D_c are casing area and diameter respectively, and n = shaft rpm/60

3. Results from Step (1) for shaft torque Q_s, shaft thrust T_s

and shaft speed rpm were then input to a program which computed shaft horsepower

$$SHP = 2\pi Q_s \; rpm/33000$$

and pump head

$$H = T_s \; / \; \rho g A_c$$

and pump efficiency

$$N_p = \rho g Q H \; / \; 550 \; SHP$$

TEST RESULTS

The results of data reduction are summarized in two series of tables. Each table in the first series lists the primary results; each table in the second series lists flow velocities across the nozzle exit which were computed from Prandtl tube pressure measurements.

Zero speed bollard pull test results appear in tables on Pages 16 through 19; these include bollard pull readings from a mechanical load cell.

Forward speed test results, including craft speed calculated from a total head tube, are listed on Pages 20 through 35.

In certain test runs, one or more of the waterjet dynamic pressure measurements was either zero or a small negative number. The corresponding flow velocity has been listed as zero with a question mark, since it was difficult to justify a near-zero velocity at any of the Prandtl tube locations in the waterjet flow cylinder. Such a reading was probably caused by a Prandtl tube/pressure transducer malfunction. Notes on Pages 14 and 15 preceding the tables of results explain how these zero values were treated in the integration of velocities to obtain waterjet flow rate.

Bollard pull measurements may be compared to waterjet thrust Tj as computed from Prandtl tube measurements of velocity distribution. However, it should be noted that waterjet flow across the Prandtl tube and tube rack, which are clamped to the testcraft, resulted in a drag force on the testcraft acting in the same direction as the bollard pull of the cable holding the craft. This drag force, which varied as the nozzle exit diameter, was estimated using a drag coefficient of 1.1; projected areas of tubes and rack; and calculated jet velocity Vj. Jet thrust has been plotted against the sum of bollard pull and measurement system drag, Figure 3.

Figure 3 shows generally good correlation between jet thrust Tj and bollard pull corrected for measurement system drag, particularly for the 14.12 - inch and 12.25 - inch waterjet exit diameters. However, results for the 10.5 - inch diameter nozzle show Tj is approximately 70 percent of corrected bollard pull; whereas results for the other two diameters fall within a band of 95 percent and 110 percent of corrected bollard pull.

While such a comparison is possible only in the zero speed bollard condition, it is reasonable to assume that flow rate Q and jet thrust Tj for 14.12 - inch and 12.25 - inch waterjet exit diameters in the free-running

testcraft should enjoy the same degree of confidence as demonstrated in the zero speed tests. Similarly, free-running test results for the 10.5 - inch diameter nozzle may be expected to understate values of Q and Tj.

CONCLUDING REMARKS

This report has documented the configuration of testcraft and waterjet propulsion system used in the July 1984 trials in New Hampshire, described the instrumentation and procedures used in the trials, and tabulated all reduced data. The tabulations have been reviewed and questionable results have been identified. It is believed that these trial results are in the form suitable for independent analysis.

Reference 2 is a companion report which presents an in-depth analysis of most of the reduced data. Trial results have been compared to design predictions of waterjet system performance, and system design procedures have been modified as appropriate.

Impeller Area Ratio: 1.50
Nozzle Exit Diam.: 12.25 in
Inlet Entrance Length: 23.0 in

mph	rpm	Ts lb	Qs ft-lb	Trim deg	Duct Pressure Fwd psi	Aft psi	Q ft³/sec	V_j ft/sec	T lb	H_p ft	SHP hp	N_p	J_c
2.70	495	141	24.9	0.9	-.11	-.43	9.25	11.32	132	2.08	2.3	0.93	0.88
4.95	848	296	78.0	-1.4	-.29	2.04	16.06	19.65	384	4.36	12.6	0.63	0.89
7.00	1109	468	122.3	5.1	-.66	-2.14	21.02	25.72	626	6.90	25.8	0.64	0.89
7.00	1106	460	121.2	4.9	-.45	-2.16	20.99	25.68	622	6.78	25.5	0.63	0.89
8.40	1394	760	193.0	5.1	-.99	-3.44	26.56	32.50	1035	11.20	51.2	0.66	0.89
8.50	1394	780	193.8	5.3	-.82	-3.30	26.20	32.06	992	11.50	51.4	0.66	0.88
10.25	1484	1150	262.1	7.2	-1.26	1.24	27.48	33.62	985	16.95	74.1	0.71	0.87
10.95	1566	1272	277.8	7.9	-1.58	6.06	29.80	36.46	1175	18.75	82.8	0.77	0.89
17.60	1723	1403	315.2	8.5	-2.79	-2.99	32.95	40.32	923	20.68	103.4	0.75	0.90
22.30	1961	1686	376.7	7.0	-2.33	-4.45	36.94	45.19	890	24.86	140.6	0.74	0.88
25.15	2101	1811	412.3	5.4	-4.97	-4.29	40.35	49.37	975	26.70	164.9	0.74	0.90
25.35	2092	1876	412.9	5.0	-5.23	-3.50	40.27	49.27	939	27.66	164.5	0.77	0.90
25.60	2400	1941	440.1	5.1	-2.40	-6.24	41.00	50.17	1001	28.62	201.1	0.66	0.80
26.25	2384	1996	435.1	6.3	-5.43	-5.52	42.05	51.45	1054	29.43	197.5	0.71	0.83

Impeller Area Ratio: 1.5
Nozzle Exit Diam: 12.25 in
Inlet Entrance Length: 19.5 in

mph	Port Side Velocities, ft/sec							0.5R	Starboard Side Velocities, ft/sec								Q, ft³/sec	
	6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R		1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Stbd
4.90	-	10.46	12.73	13.69	10.56	12.98	12.81	11.24	9.62	12.05	13.69	13.22	13.22	13.30	10.00	-	10.23	10.52
4.20	-	13.30	15.01	13.30	14.94	14.73	14.66	12.81	12.40	12.23	14.29	14.51	14.73	14.94	10.91	-	11.91	11.51
4.85	-	19.03	21.42	19.95	20.93	20.31	20.72	16.22	16.67	17.59	19.95	20.77	21.18	21.57	17.68	-	17.05	16.59
5.15	-	17.11	19.52	18.01	19.25	18.92	18.35	14.80	14.87	15.89	16.98	18.58	18.69	18.75	14.65	-	15.50	14.49
5.35	-	20.77	22.62	19.89	16.80	17.65	6.21	0.?	0.?	19.47	19.74	19.63	21.08	22.38	19.22	-	15.65	15.42
5.40	-	17.47	20.47	19.47	17.83	19.63	19.14	16.86	17.23	19.41	20.47	19.63	19.79	19.89	16.06	-	15.92	16.19
7.80	-	26.36	30.61	28.76	30.37	29.74	29.74	26.83	27.34	26.20	27.26	29.34	29.38	29.42	23.6.	-	24.46	23.42
8.35	-	25.91	29.77	29.31	25.21	29.27	29.02	21.81	24.79	27.76	27.91	29.24	29.24	29.24	23.26	-	23.47	23.31
9.25	-	34.67	36.74	31.76	32.90	30.81	15.89	6.73	21.42	29.27	31.59	33.50	35.30	37.02	30.61	-	26.71	26.63
10.25	-	35.63	37.16	32.80	29.66	30.54	12.65	1.78	17.41	30.78	32.73	34.61	36.32	38.06	31.44	-	30.36	26.07
15.50	-	41.22	43.87	38.74	38.93	36.56	15.22	2.71	20.26	35.06	39.15	40.63	42.60	44.56	36.63	-	31.69	30.55
18.40	-	43.89	45.93	40.76	41.06	38.80	20.72	14.76	28.47	37.72	41.83	43.02	45.65	48.14	38.80	-	33.75	34.64
19.00	-	43.04	45.54	42.00	38.50	38.53	19.14	6.73	23.89	38.44	41.19	42.85	45.68	48.34	40.24	-	33.28	34.33
20.05	-	44.66	48.28	41.90	42.48	40.52	17.89	2.51	21.76	37.53	41.95	44.25	47.11	49.82	39.47	-	34.69	34.54
20.05	-	43.33	47.53	41.98	38.69	40.60	19.68	6.73	24.54	38.36	42.03	43.60	46.39	49.01	40.64	-	33.96	34.81
21.90	-	38.58	44.18	41.90	45.31	44.82	40.94	34.69	38.96	40.50	45.14	47.86	50.07	52.19	37.54	-	35.73	38.09

Impeller Area Ratio 1.5
Nozzle Exit Diam 12.25 in
Inlet Entrance Length 19.5 in

mph	rpm	Ts lb	Qs ft-lb	Trim deg	Duct Pressure Fwd psi	Aft psi	Q ft³/sec	VJ ft/sec	TJ lb	HP ft	SHP np	Np	Jc
4.30	610	199	39.3	1.0	1.85	-.36	10.37	12.69	128	2.93	4.6	0.76	0.80
4.20	643	206	42.7	1.3	-.26	-.48	11.71	14.33	184	3.04	5.2	0.77	0.85
4.85	862	470	95.5	-1.6	-.57	-.89	16.82	20.58	437	6.93	15.7	0.84	0.92
5.15	795	311	67.2	1.3	-.61	-1.25	14.99	18.35	313	4.59	10.2	0.77	0.88
5.35	883	497	97.4	-1.6	-.99	-1.62	15.54	19.01	336	7.33	16.4	0.79	0.83
5.40	892	493	94.1	-1.8	1.27	-.89	16.06	19.65	363	7.27	16.0	0.83	0.84
7.80	1245	694	156.8	6.0	-1.40	-2.51	23.94	29.29	824	10.23	37.2	0.75	0.90
8.25	1257	693	160.6	5.6	-1.35	-2.61	23.39	28.62	747	10.22	38.4	0.71	0.87
9.25	1426	1047	234.8	6.2	-2.00	-3.10	26.67	32.63	982	15.44	63.7	0.73	0.88
10.25	1458	1175	252.2	7.5	-1.71	-2.68	26.21	32.03	863	17.32	70.0	0.74	0.84
15.50	1678	1489	329.1	7.4	-3.26	-3.09	31.12	38.02	921	21.95	105.1	0.74	0.87
18.40	1875	1786	385.2	9.2	-4.73	-3.60	34.20	41.84	979	26.33	137.5	0.74	0.86
19.00	1849	1728	374.0	8.5	-2.20	-3.74	33.81	41.36	884	25.48	131.7	0.74	0.86
20.05	1872	1699	374.5	7.9	-4.89	-3.78	34.62	42.35	866	25.05	133.5	0.74	0.87
20.05	1873	1710	366.2	7.3	-2.21	-4.02	34.38	42.07	843	25.21	130.6	0.75	0.86
21.90	2412	1966	417.9	7.9	-6.40	-5.70	36.91	45.16	928	28.98	191.9	0.63	0.72

Bollard Pull Tests
Impeller Area Ratio: 2.25
Inlet Entrance Length: 33.in

Nozzle in	rpm	Port Side Velocities, ft/sec							Starboard Side Velocities, ft/sec									Q, ft³/sec	
		6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Stbd
14.12	619	10.86	11.70	11.79	11.24	10.46	9.51	10.66	0.?	7.81	9.29	11.05	11.52	11.96	12.31	11.70	10.86	11.25	11.21
	915	16.64	17.59	17.53	16.61	15.63	14.58	16.16	0.?	11.05	12.14	15.96	16.48	17.35	18.18	17.59	16.64	16.90	16.34
	1218	23.19	24.24	24.15	22.05	20.57	20.10	16.80	0.?	0.?	16.22	20.83	20.83	22.38	23.80	24.24	23.19	22.64	20.75
	1486	29.16	30.23	30.40	27.03	25.30	24.75	19.25	0.?	3.24	20.10	26.24	25.83	27.91	29.84	30.23	29.16	28.03	26.17
	1806	36.58	37.56	37.70	34.15	31.19	30.95	23.22	0.?	4.10	20.62	28.95	30.30	33.15	35.78	37.56	36.58	34.92	30.97
	2085	43.69	45.21	44.89	39.92	35.21	28.62	13.14	0.?	6.96	22.10	30.12	33.40	36.62	39.55	45.21	43.69	39.29	35.12
12.25	601	-	11.61	13.61	12.90	13.53	12.98	13.92	11.42	12.23	11.96	13.30	13.69	13.61	13.46	7.25	-	10.91	10.39
	874	-	20.42	22.85	20.72	20.62	17.77	0.?	0.?	0.?	16.86	19.95	20.42	21.00	21.57	10.81	-	15.82	14.07
	1224	-	29.66	33.56	28.98	28.51	15.69	0.?	0.?	0.?	22.48	26.99	28.02	29.59	31.09	11.29	-	21.50	18.98
	1497	-	35.84	41.55	35.42	34.52	18.75	0.?	0.?	0.?	26.99	32.28	34.34	36.24	38.03	8.71	-	26.21	22.40
	1828	-	42.33	51.54	43.77	42.08	23.58	0.?	0.?	0.?	31.99	40.65	42.13	44.49	46.70	6.81	-	32.13	27.02
	2085	-	50.62	60.09	51.63	47.28	25.42	0.?	0.?	0.?	36.36	46.45	47.99	50.89	53.63	9.89	-	37.24	31.15
10.50	604	-	-	-	17.04	18.92	7.11	7.40	4.92	0.?	8.21	17.17	14.44	10.26	-	-	-	7.54	6.80
	897	-	-	-	19.89	22.94	0.?	5.43	0.?	0.?	0.?	23.26	23.53	16.67	-	-	-	?	?
	1202	-	-	-	34.73	30.75	0.?	5.80	17.41	8.21	7.11	30.16	30.85	22.00	-	-	-	?	13.10
	1513	-	-	-	44.37	36.76	12.31	5.43	15.69	7.68	9.62	38.00	38.61	27.53	-	-	-	16.06	16.20
	1623	-	-	-	48.04	37.98	9.62	5.80	5.80	7.11	0.?	39.50	41.40	35.54	-	-	-	16.70	?

Bollard Pull Tests
Impeller Area Ratio: 2.25
Inlet Entrance Length: 33 in

Nozzle in	rpm	Ts lb	Qs ft-lb	Duct Pressure Fwd psi	Aft psi	Pull lb	Q ft³/sec	VJ ft/sec	TJ lb	Hp ft	SHP hp	Np	Jc
14.12	619	168	32	- .08	- .74	200	11.23	10.33	224	2.48	3.7	0.84	0.85
	915	336	70	- .29	- 1.70		16.62	15.29	491	4.95	12.2	0.76	0.85
	1218	620	136	- .51	- 3.24	700	21.70	19.96	836	9.14	31.6	0.71	0.84
	1486	909	209	- .85	- 5.57	1100	27.10	24.93	1304	13.40	59.2	0.70	0.86
	1806	1338	305	-1.32	- 8.09	1750	32.95	30.3?	1927	19.73	104.9	0.70	0.86
	2085	1677	381	-1.61	-10.71	2250	37.20	34.23	2457	24.72	151.1	0.69	0.84
12.25	601	55	14	- .07	- 1.12	200	10.65	13.03	269	0.81	1.6	0.63	0.83
	874	315	71	- .21	- 1.55	400	14.94	18.26	529	4.64	11.9	0.66	0.80
	1224	768	162	- .41	- 2.03	800	20.24	24.76	967	11.32	37.9	0.69	0.78
	1497	1229	269	- .65	- 3.69	1300	24.31	29.74	1395	18.12	76.6	0.65	0.76
	1828	1869	410	-1.02	- 5.89	2000	29.57	36.18	2065	27.55	142.8	0.65	0.76
	2085	2380	537	-1.35	- 8.08	2700	34.20	41.84	2761	35.09	213.1	0.64	0.77
10.50	604	364	66	- .09	- .46	200	7.17	11.87	164	5.37	7.6	0.57	0.56
	897	820	160	- .15	- .52	350	?	?	?	12.09	27.4	?	?
	1202	1501	293	- .27	- 1.07	700	13.10	21.80	554	22.13	67.0	0.49	0.51
	1513	2333	479	- .51	- 1.54	1100	16.13	26.71	831	34.40	138.1	0.46	0.50
	1623	2592	548	- .55	- 2.14	1250	16.70	27.80	901	38.21	169.5	0.43	0.48

Bollard Pull Tests
Impeller Area Ratio: 1.50
Nozzle Exit Dia.: 12.25

Inlet in	rpm	Port Side Velocities, ft/sec							Starboard Side Velocities, ft/sec									Q, ft³/sec	
		6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Stbd
19.5	630	-	14.94	16.54	15.42	15.15	13.38	5.03	0.?	0.?	11.79	14.22	14.87	15.29	15.63	13.10	-	12.00	10.82
	910	-	23.44	25.87	22.90	21.81	15.49	0.?	0.?	0.?	15.08	20.62	20.98	21.96	22.90	19.03	-	17.10	15.40
	1211	-	32.02	35.42	29.84	28.80	16.09	0.?	0.?	0.?	18.35	26.52	28.10	29.47	30.85	25.73	-	22.39	19.49
	1500	-	39.23	43.21	36.42	35.48	18.35	0.?	0.?	0.?	20.88	31.79	34.76	37.36	39.79	30.02	-	27.25	24.84
	1819	-	48.67	53.84	44.13	41.32	24.02	0.?	0.?	4.35	27.68	40.21	42.20	45.19	47.97	31.10	-	33.36	30.19
	2042	-	57.05	62.81	49.10	44.89	22.43	2.90	6.88	10.66	35.89	46.84	47.95	51.20	54.23	32.86	-	37.58	35.12
23	633	-	10.56	11.79	10.95	10.76	9.95	2.05	0.?	0.?	7.95	10.16	10.36	10.76	11.05	9.89	-	8.47	7.68
	919	-	22.38	24.28	20.52	19.68	12.57	0.?	0.?	0.?	11.24	18.24	18.58	20.10	21.47	19.33	-	15.57	13.95
	1213	-	30.92	33.53	28.25	26.40	11.96	0.?	0.?	0.?	16.73	24.92	26.36	27.98	29.52	25.42	-	20.78	19.29
	1518	-	38.85	41.95	35.39	33.78	15.96	0.?	0.?	0.?	20.47	31.52	33.59	36.42	38.96	29.75	-	26.26	24.35
	1840	-	48.01	53.43	43.99	39.76	22.62	0.?	0.?	0.?	25.83	39.89	41.80	45.07	48.01	29.79	-	32.79	29.42
	2059	-	55.86	62.86	49.05	43.46	18.75	0.?	0.?	3.55	35.24	45.72	48.19	51.20	54.02	32.15	-	36.60	34.17
33	587	-	13.69	15.08	13.99	14.22	13.22	9.18	0.?	5.80	11.14	13.46	14.07	13.30	12.48	11.42	-	11.44	10.09
	920	-	23.89	26.12	22.66	22.38	16.16	0.?	0.?	0.?	14.51	20.77	21.08	20.52	19.74	18.89	-	17.32	14.82
	1215	-	32.12	34.97	29.66	28.36	17.17	0.?	0.?	0.?	20.00	26.68	28.47	31.05	33.43	25.21	-	22.28	20.99
	1507	-	39.82	42.97	36.53	35.00	20.05	0.?	0.?	0.?	22.62	32.28	34.52	37.14	39.76	29.86	-	27.42	24.06
	1827	-	48.62	53.49	44.65	41.12	25.63	2.90	20.90	5.98	29.77	39.63	42.03	45.90	49.76	29.24	-	33.75	30.75
	2055	-	55.42	62.37	50.37	45.45	22.66	2.05	26.60	8.71	36.48	46.95	48.97	51.95	54.77	31.72	-	37.59	36.39

BOLLARD PULL TESTS
Impeller Area Ratio: 1.50
Nozzle Exit Diam.: 12.25 in

Inlet .in	rpm	T_s lb	Q_s ft-lb	Duct Pressure Fwd psi	Aft psi	Pull lb	Q ft³/sec	V_j ft/sec	T_j lb	H_p ft	SHP hp	N_p	J_c
19.5	630	204	52	-.13	-.86	200	11.41	13.97	308	3.01	6.3	0.62	0.85
	910	502	112	-.25	-1.56	500	16.25	19.88	624	7.40	19.4	0.70	0.84
	1211	919	202	-.47	-2.87	850	20.94	25.58	1038	13.55	46.6	0.69	0.81
	1500	1464	315	-.73	-4.76	1400	26.04	31.87	1602	21.58	90.1	0.71	0.81
	1819	2096	466	-1.05	-6.76	2100	31.71	38.80	2374	30.90	161.3	0.69	0.82
	2042	2638	569	-1.48	-8.67	2700	36.35	44.48	3120	38.89	221.2	0.73	0.83
26	633	168	26	-.09	-.56	200	8.07	9.88	154	2.48	3.1	0.73	0.60
	919	458	89	-.20	-1.28	500	14.76	18.06	514	6.75	15.6	0.72	0.75
	1213	667	173	-.37	1.17	850	20.04	24.52	948	12.78	40.0	0.73	0.77
	1518	1430	293	-.64	-4.31	1400	25.30	30.96	1512	20.94	84.6	0.71	0.78
	1840	2125	447	-1.07	-6.72	2200	31.10	38.05	2284	31.33	156.5	0.71	0.79
	2059	2659	548	-1.50	-8.49	2800	35.38	43.29	2956	39.20	214.8	0.73	0.81
33	557	252	46	-.12	-.60	200	10.77	13.17	274	3.42	5.2	0.81	0.86
	950	552	114	-.27	-1.38	500	16.07	19.66	610	7.84	20.0	0.72	0.82
	1247	903	199	-.45	-2.70	950	21.06	26.51	1108	14.15	46.1	0.75	0.84
	1547	1400	297	-.50	-1.75	1400	25.74	31.45	1508	21.60	88.0	0.72	0.80
	1840	2115	456	-.39	-6.37	2170	31.37	38.96	2439	31.37	160.3	0.71	0.82
	2059	2630	569	-1.50	-8.47	2700	36.35	44.80	3195	34.47	221.0	0.74	0.84

WATERJET VELOCITIES

In any run for which one or more zero velocity readings are listed, these readings have been included in the integration for flow rate, provided that the total annular area involved is equal to or less than 14 percent of the nozzle exit area. For example, on Page 21 the test run at 5.35 mph shows zero velocities at 0.5-inch and 1.5-inch radius locations on the starboard side. The total area is that for a circle of 2-inch radius or 0.0873 square feet. Since this is only 11 percent of the 12.25-inch diameter nozzle area of 0.818 square feet, the zero velocities were included in the flow rate integration.

However, if zero readings are associated with a total annular area equal to or greater than 15 percent of the nozzle exit area, an integration of the velocities over the remaining area would yield an unacceptable underestimate of flow rate. In such cases, a question mark had been inserted in place of a flow rate. If for example, a port side flow rate is reported but question mark appears in place of the corresponding starboard side rate, the average rate would be taken equal to the reported port side flow rate. If both port and starboard rates are in question, no flow rate is listed and all quantities derived from flow rate are replaced by question marks.

EXPLANATORY NOTES FOR TABLES

<u>Column Captions</u>

mph   craft speed through water in statute miles per hour

rpm   impeller shaft revolutions per minute

Ts   impeller shaft thrust

Qs   impeller shaft torque

Trim running trim relative to a static floating trim of approximately zero deg.

psi   static pressure change relative to atmospheric at 1500 ft above sea level.

Pull bollard pull during zero speed test

Q   flow rate

Vj   waterjet mean velocity

Tj   waterjet thrust

Hp   pump head

SHP   impeller shaft horsepower

Np   pump efficiency

Jc   impeller advance coefficient in casing

An inclinometer was installed parallel to the craft baseline to sense change in trim from a static floating datum.

A Dillon mechanical load cell with a 5000 lb capacity and a dial indicator resolvable to 50 lb, was used to measure bollard pull.

DATA LOGGER

The dc voltage output of each of 24 transducers was passed through a buffer to compensate for any zero offset and to provide a measure of time averaging of the signal. The signal was then input to a data logger (Doric Digitrend 210) which digitized, stored, and then printed a digital output on paper tape. A sequential printing of 24 channels took about 20 seconds. The logger was usually programmed to start a sequential printout upon pushbuttom command and then stop automatically after the 24th channel output was printed. The vehicle driver started the data logger by pushing on a button protruding from the front of the instrument box, Figure 1.

APPENDIX B

INSTRUMENTATION DETAILS

ELECTRIC POWER

A 12 volt engine battery energized a ±15 volt power supply dedicated to all instrumentation.

TORQUE THRUST DYNAMOMETER

A transmission-type dynamometer was designed and constructed by Specialty Measurements, Inc. with ratings of 5000 lb of thrust, 600 ft-lb of torque and maximum speed of 4000 rpm. Builder's calibrations were confirmed by performing static thrust and torque loads in the Davidson Laboratory instrument shop; shunt resistances were used as calibration signals during the trials. A magnetic speed pickup was built into the dynamometer and its frequency output was converted to a dc voltage.

OTHER TRANSDUCERS

A pressure transducer of the "wet-wet differential" type (Schaevitz P-3000 Series) was coupled to a Prandtl tube to furnish a voltage output proportional to the difference between static head and total head sensed by the Prandtl tube. Sixteen Prandtl tube/transducer sets were used to obtain up to 16 fluid velocity readings across the horizontal centerline plane of impeller discharge flow; transducer ratings of 15 psi or 50 psi were used depending on the Prandtl tube location.

Two 15 psi transducers were connected to static pressure taps in the inlet duct ahead of the impeller. A total head tube, attached to the port rudder and projecting ahead of the leading edge of the rudder, was connected to a 15 psi transducer to sense craft speed. All pressure transducers were bench calibrated before the trials and check calibrations were performed during the trial. Prandtl tube/transducer units were towed in a model basin to check their inherent calibrations.

Two wooden inserts were fabricated to reduce the opening of the flush inlet from its designed length of 33 inches to lengths of 19-1/2 inches. and 23 inches respectively.

Three impellers were fabricated by Michigan Wheel, according to the following specifications:

Diameter, D	14.00 in
Pitch	14.00 in
Projected Area Ratios	1.00, 1.50, 2.25
Hub	2.80-in dia x 11.75-in length
Number of Blades	3
Blade Thickness	0.045D

The propulsion assembly consisted of:

- An 8 cylinder, vee block, Chris Craft engine (Model 45415) with a 1.5:1 gear reduction ratio. Rated power was 330 hp with a top engine rpm of 4200 rpm (2800 propeller shaft rpm).

- Port and starboard exhaust pipes at deck level at the aft end of the engine compartment.

- A 12 volt battery.

- A cooling water scoop at the forward end of the engine compartment keel.

- A flexible coupling between the engine shaft and tailshaft.

The driver's console included a steering wheel to control the actuators for the two rudders; a control lever to change transom flap angle; a throttle control lever; and a bank of dials displaying generator current, engine water temperature, and engine rpm. Also, switches for bilge pumps and a bilge ventilation blower. Rudders with 11 inch chord were pivoted from the port and starboard transom corners, extending from deck level to 14 inches below the keel.

APPENDIX A

TESTCRAFT DESCRIPTION

The testcraft hull, Figure 1, was configured to represent a 0.55-scale model of a proposed high-speed amphibian, "Tack Hammer". For convenience of construction and assembly, the hull consisted of three units:

- A bow section with a "bow plate" constructed of aluminum alloy plate attached to the hull bow with hinged tie rods.

- An engine compartment containing the engine assembly and the driver's console.

- A pump box containing the waterjet inlet,, pump impeller and casing, gasoline storage tank, rudders and rudder actuators transom flaps and flap actuators, and driver's cockpit.

A boat trailer, dedicated to the testcraft, permitted the testcraft to be launched from any recreational boat marina ramp.

The waterjet system consisted of:

- A flush inlet in the form of a 33 inch-long by 14.12 inch width rectangle.

- A transition duct with a 17.06 inch height by 14.12 inch width rectangular inlet and a 14.12 inch circular outlet.

- A 14.12 inch I.D. by 3 inch long cylinder in which were housed four equally spaced radial struts supporting a shaft bearing housing.

- A 14.12 inch I.D. cylindrical casing which housed a 14 inch diameter impeller.

- A nozzle with an inlet/discharge area ratio of 1.8/1; an alternate nozzle of the same length with an area ratio 1.33/1; exit diameters were 10.5 inches and 12.25 inches, respectively.

The bearing support ring, struts and bearing housing were constructed of aluminum alloy; the impeller was manganese bronze. Inlet, transition, casing and nozzles were molded of fiberglass/polyester resin laminate.

REFERENCES

1. Numata, E., "Performance Trial of a Manned Waterjet Testcraft", Davidson Laboratory Report 2390, March 1984.

2. Roper, J.K. "Design Procedure for Low Speed Waterjets Suitable for Application in Amphibious Vehicles", Davidson Laboratory Report 2518, November 1984.

Impeller Area Ratio: 1.50
Nozzle Exit Diam.: 12.25 in
Inlet Entrance Length: 23.0 in

mph	Port Side Velocities, ft/sec							0.5R	Starboard Side Velocities, ft/sec								Q, ft³/sec	
	6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Std
2.70	-	10.66	12.05	11.14	9.06	11.96	11.24	9.57	9.51	10.66	11.33	11.79	11.79	11.79	9.23	-	9.18	9.32
4.95	-	17.71	20.26	19.57	18.64	19.74	20.52	15.39	16.42	17.53	19.89	20.26	20.21	20.16	15.83	-	16.17	15.95
7.00	-	22.90	26.83	25.87	22.94	25.87	26.44	19.17	22.34	22.85	25.42	26.79	26.60	26.40	22.17	-	20.96	21.05
7.00	-	23.03	26.79	25.87	23.08	25.59	26.44	18.97	22.29	23.12	25.30	26.75	26.48	26.16	22.00	-	20.99	20.99
8.40	-	28.47	33.21	33.09	31.42	32.86	32.57	23.51	27.95	29.66	31.79	33.31	33.21	33.15	27.49	-	26.74	26.39
8.50	-	30.02	33.75	32.93	31.15	32.25	30.44	12.69	23.31	28.58	31.79	33.28	33.18	33.05	27.18	-	26.74	25.65
10.25	-	37.22	37.47	33.78	31.32	30.98	12.65	0.0	15.96	30.12	34.49	35.98	37.72	39.39	32.83	-	27.12	27.84
10.95	-	36.51	41.73	38.50	33.78	34.37	20.42	2.29	21.72	32.54	34.76	37.28	39.47	41.55	35.85	-	29.99	29.60
17.60	-	41.73	47.79	41.27	37.56	37.72	21.03	3.55	23.35	36.10	39.95	41.29	43.02	44.67	38.80	-	33.27	32.64
22.30	-	46.00	52.40	48.19	42.35	42.25	23.03	10.86	31.82	41.32	45.26	45.95	47.59	49.16	39.39	-	37.36	36.52
25.15	-	50.03	56.31	51.93	45.65	45.54	28.65	24.54	39.19	44.18	49.80	49.20	50.47	53.69	43.14	-	40.57	40.13
25.35	-	47.68	54.93	52.64	46.93	44.86	25.96	21.88	40.76	44.67	50.16	50.03	51.75	53.41	42.71	-	40.09	40.45
25.60	-	46.04	51.91	50.30	46.77	47.02	42.35	36.48	41.83	44.98	51.54	52.44	53.84	55.19	41.54	-	40.28	41.73
26.25	-	47.31	54.79	52.44	49.46	47.11	42.55	38.40	43.65	44.34	50.82	51.93	54.06	56.08	45.53	-	41.80	42.30

Impeller Area Ratio: 1.5
Inlet Entrance Length: 35.in

Nozzle in	mph	rpm	Ts lb	Ws ft-lb	Trim deg	Duct Pressure Fwd psi	Aft psi	Q ft³/sec	VJ ft/sec	TJ lb	Hp ft	SHP hp	Np	Jc
12.25	2.70	637	207	44.2	1.1	.11	-.61	14.02	14.71	219	3.05	5.4	0.78	0.89
	4.50	860	447	92.8	-2.1	.05	-1.16	17.05	20.86	470	6.59	15.2	0.84	0.93
	4.55	872	453	94.5	-2.3	.03	-1.19	16.27	19.90	416	6.68	15.7	0.79	0.87
	7.50	1296	718	160.1	3.4	.10	-2.52	25.43	31.12	988	10.59	39.5	0.77	0.92
	10.70	1495	1150	250.0	8.1	.20	-2.64	29.27	35.81	1135	16.95	71.2	0.79	0.92
	21.60	1894	1536	333.9	6.2	.84	-3.11	38.06	46.57	1096	22.65	120.4	0.81	0.94
	24.80	2146	1927	434.8	7.1	-.01	-3.43	42.12	51.53	1232	28.41	177.7	0.76	0.92
10.50	3.95	584	243	45.0	0.8	.03	-2.58	9.13	15.11	165	3.58	5.0	0.74	0.73
	4.70	652	292	55.9	1.0	-.08	-2.68	10.24	16.95	199	4.30	6.9	0.72	0.74
	4.85	842	748	140.5	-1.2	.01	-2.56	11.79	19.52	282	11.03	22.5	0.65	0.66
	12.80	1463	1942	407.4	7.2	.25	-2.46	18.70	30.97	440	28.63	113.5	0.54	0.60
	12.10	1604	2325	492.6	8.6	.34	-2.58	18.63	30.85	470	34.28	150.4	0.48	0.54
	19.00	1621	2196	463.3	7.4	-.89	-2.38	20.23	33.50	222	32.38	143.0	0.52	0.59
	20.55	1643	2184	460.8	7.3	-1.25	-2.18	21.41	35.45	219	32.20	144.1	0.54	0.61
	25.10	1809	2470	551.6	4.8	-1.58	-1.34	24.11	39.92	146	36.42	190.0	0.52	0.63
	25.50	1805	2485	546.0	4.5	-1.64	-1.68	25.18	41.90	218	36.64	187.6	0.56	0.65
	26.75	1827	2541	546.2	5.8	-2.16	-2.46	24.99	41.38	104	37.46	190.0	0.56	0.64

Impeller Area Ratio: 1.5
Inlet Entrance Length: 33. in

Nozzle in	rpm	Port Side Velocities, ft/sec							0.5R	Starboard Side Velocities, ft/sec								Q, ft³/sec	
		6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R		1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Stbd
12.25	637	-	12.90	14.80	14.14	14.73	13.69	17.17	8.34	15.83	10.56	15.29	14.80	15.49	16.16	12.05	-	12.02	12.02
	860	-	17.89	21.76	20.10	21.23	20.26	22.29	15.15	18.97	16.22	21.03	20.93	22.38	23.08	16.86	-	17.14	16.96
	872	-	20.98	22.94	20.62	20.52	18.18	7.11	5.43	4.81	17.11	19.52	20.26	22.71	24.92	18.95	-	16.43	16.11
	1296	-	25.87	31.09	30.68	31.62	31.22	31.32	22.76	27.80	28.40	30.88	31.69	32.83	33.93	24.73	-	25.32	25.54
	1495	-	36.53	42.00	38.80	35.78	34.46	14.94	12.31	15.76	31.19	34.03	36.88	39.36	41.70	31.05	-	30.03	28.51
	1894	-	45.14	49.97	48.04	47.71	46.61	37.56	6.96	31.39	40.39	43.48	45.61	50.01	54.06	40.69	-	39.13	37.00
	2146	-	51.61	56.20	53.35	53.37	51.32	41.75	8.40	29.49	45.79	49.29	50.07	54.41	58.42	43.96	-	43.78	40.45
10.50	584	-	-	-	15.96	17.53	17.65	18.69	0.?	17.83	16.16	17.35	16.42	11.61	-	-	-	9.08	9.17
	652	-	-	-	18.52	19.19	19.03	18.92	0.?	18.41	15.89	19.84	20.57	14.51	-	-	-	10.00	10.47
	842	-	-	-	26.00	28.51	25.05	0.?	0.?	0.?	17.71	25.96	25.09	17.77	-	-	-	12.19	11.39
	1463	-	-	-	50.66	46.63	18.35	0.?	0.?	7.11	15.22	44.93	42.70	30.19	-	-	-	19.07	18.34
	1604	-	-	-	53.35	47.66	9.73	0.?	0.?	6.81	6.81	46.81	46.16	32.64	-	-	-	18.82	18.44
	1621	-	-	-	53.47	50.76	22.24	2.05	0.?	9.40	18.41	47.68	44.41	31.46	-	-	-	20.82	19.64
	1643	-	-	-	54.70	52.60	26.71	2.05	0.?	9.40	25.75	49.35	45.68	32.44	-	-	-	21.83	20.98
	1809	-	-	-	60.45	56.66	26.36	0.?	0.?	10.56	39.15	55.04	52.31	36.99	-	-	-	23.40	24.82
	1805	-	-	-	60.52	56.66	29.42	4.10	0.?	11.14	34.70	54.89	53.19	37.61	-	-	-	24.04	26.33
	1827	-	-	-	60.70	59.74	34.82	2.05	0.?	7.40	37.13	56.29	54.11	38.39	-	-	-	24.99	24.99

25

Impeller Area Ratio: 1.5
Inlet Entrance Length: 33.in

Nozzle in	mph	rpm	Ts lb	Qs ft-lb	Trim deg	Duct Pressure Fwd psi	Aft psi	Q ft³/sec	Vj ft/sec	TJ lb	Hp ft	SHP hp	Np	Jc
14.12	3.45	499	*	16.2	0.4	-.08	-.54	13.16	12.11	178	*	1.5	*	0.72
	4.50	600	163	30.7	2.9	.10	-.38	9.70	8.93	44	2.40	3.5	0.75	0.76
	5.00	900	244	57.7	0.5	-.18	-1.49	16.53	15.21	251	3.60	9.9	0.68	0.86
	7.55	1301	392	108.7	5.1	-.32	-3.73	24.58	22.62	547	5.78	26.9	0.60	0.89
	8.60	1493	617	158.1	5.3	-.36	-4.68	25.99	23.91	567	5.10	44.9	0.60	0.82
	11.10	1768	864	210.1	6.9	-.31	-6.35	31.47	28.95	769	12.74	70.7	0.64	0.83
	11.60	1765	852	212.5	7.4	-.35	-6.27	33.51	30.83	894	12.56	71.4	0.67	0.89
	12.80	1872	904	230.2	8.1	-.20	-7.01	33.10	30.45	748	13.33	82.0	0.61	0.83
	12.75	1876	931	228.7	7.7	-.22	-6.98	32.51	29.91	703	13.73	81.7	0.62	0.81
	15.10	2090	1053	263.7	7.2	.01	-8.67	36.37	33.46	794	15.52	104.9	0.61	0.82
	21.75	2266	1124	279.5	6.8	1.34	-8.32	42.83	39.40	622	16.57	120.6	0.67	0.89
	23.25	2449	1165	281.5	5.5	1.65	-9.14	43.52	40.04	502	17.18	131.3	0.65	0.83

* Unreliable data

Impeller Area Ratio 1.5
Inlet Entrance Length 33 in

Nozzle in	rpm	Port Side Velocities, ft/sec							Starboard Side Velocities, ft/sec									Q, ft³/sec	
		6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Stbd
14.12	499	19.03	10.16	11.52	12.14	10.46	11.52	7.95	16.80	10.76	10.66	11.61	13.30	12.48	11.52	10.10	19.03	12.74	13.58
	600	11.24	11.61	9.51	8.71	9.18	5.80	9.62	0.?	6.96	5.23	9.06	6.81	10.36	12.90	11.38	11.24	9.74	9.67
	900	17.41	17.53	17.29	16.86	16.22	14.65	7.40	0.?	13.38	12.81	16.48	16.29	16.73	17.17	17.35	17.41	16.52	16.55
	1301	22.36	26.08	26.71	25.09	24.28	23.40	20.83	26.73	20.67	20.52	25.01	26.36	23.26	19.63	25.19	22.36	24.98	24.18
	1493	22.03	30.85	29.81	27.83	25.83	25.01	20.83	30.93	20.98	24.28	26.68	28.28	22.52	14.65	28.56	22.03	27.04	24.94
	1768	26.12	36.85	35.39	32.64	30.64	29.63	24.62	32.36	25.55	28.43	30.75	32.96	30.47	27.72	33.92	26.12	32.02	30.92
	1765	35.24	36.48	35.03	32.70	30.40	29.77	24.79	32.49	25.21	28.40	30.78	33.15	32.54	31.89	33.93	35.24	33.64	33.38
	1872	23.86	38.22	37.13	34.88	32.67	31.49	26.36	22.66	27.34	29.91	32.67	34.79	35.98	37.13	35.50	23.86	33.16	33.08
	1876	20.31	38.55	37.16	34.85	32.54	31.66	26.83	23.08	27.49	30.19	32.83	34.88	36.04	37.16	35.42	20.31	32.56	32.45
	2090	24.98	41.80	41.27	39.18	36.39	34.79	28.28	25.13	31.36	33.56	35.87	37.98	39.66	41.27	38.99	24.98	36.47	36.36
	2266	43.48	44.58	43.46	41.40	39.60	37.64	31.85	33.58	35.66	38.69	40.63	43.41	43.55	43.70	42.35	43.48	42.21	43.45
	2499	44.08	43.33	44.74	41.78	38.42	37.98	32.70	33.86	38.31	40.76	41.95	44.89	43.96	43.04	44.83	44.08	42.37	44.67

27

Impeller Area Ratio 2.25
Exit Diam 14.12 in
Inlet Entrance Length 33. in

mph	rpm	Ts lb	Qs ft-lb	Trim deg	Duct Pressure Fwd psi	Aft psi	Q ft³/sec	VJ ft/sec	TJ lb	Hp ft	SHP hp	Np	Jc
4.65	620	162	33.3	2.7	.03	-.52	10.91	10.03	68	2.39	3.9	0.75	0.83
5.70	881	253	53.7	2.7	-.04	-1.20	16.02	14.73	196	3.73	9.0	0.75	0.85
6.80	1130	334	86.6	5.4	-.11	-2.41	22.07	20.30	442	4.92	18.6	0.66	0.92
8.95	1520	668	169.4	5.2	-.39	-4.63	28.57	26.28	727	9.85	49.0	0.65	0.88
8.75	1526	667	171.8	5.7	.24	-4.72	28.77	26.47	756	9.83	49.9	0.64	0.88
11.70	1822	876	224.5	9.2	-.20	-6.62	34.08	31.35	932	12.91	77.9	0.64	0.88
11.80	1835	859	229.1	9.6	-.21	-6.70	34.23	31.49	939	12.66	80.0	0.61	0.87
12.55	1937	955	251.7	8.3	-.21	-7.61	35.93	33.05	1018	14.08	92.8	0.62	0.87
14.70	2093	1032	281.2	7.1	.09	-8.62	39.06	35.93	1082	15.21	112.1	0.60	0.88
15.00	2117	1046	282.4	6.4	-.03	-8.90	39.53	36.36	1097	15.42	113.8	0.61	0.88
16.20	2234	1102	287.2	7.8	.18	-9.19	40.93	37.66	1101	16.25	122.2	0.62	0.86
15.65	2236	1134	291.4	6.5	.06	-9.19	40.69	37.44	1138	16.72	124.1	0.62	0.85
15.35	2244	1066	290.9	7.8	.04	-9.01	40.74	37.48	1177	15.72	124.3	0.58	0.85
15.71	2248	1089	297.0	7.6	.05	-9.21	40.71	37.45	1089	16.06	127.1	0.58	0.85
16.30	2494	1089	298.4	6.3	.12	-9.39	41.36	38.05	1132	16.06	141.7	0.53	0.78
16.40	2477	1162	304.4	7.4	.13	-9.52	41.52	38.19	1136	17.13	143.6	0.56	0.79

Impeller Area Ratio: 2.25
Exit Diam: 14.12 in
Inlet Entrance Length: 33 in

mph	Port Side Velocities, ft/sec 6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R	0.5R	Starboard Side Velocities, ft/sec 1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Q, ft³/sec Port	Stbd
4.65	8.46	11.79	11.52	11.70	10.95	9.95	10.46	7.11	10.16	10.26	11.52	11.70	11.61	11.52	11.79	6.88	10.96	10.86
5.70	13.65	16.92	16.80	16.48	15.76	14.22	14.65	9.00	13.84	13.99	16.35	16.29	16.54	16.80	16.92	13.65	15.97	16.06
6.80	22.45	22.52	22.10	21.37	21.13	20.21	20.31	13.92	17.35	16.98	21.57	21.72	22.22	22.71	22.52	22.45	22.13	22.02
8.95	30.14	30.54	28.84	27.14	26.28	25.09	23.75	12.05	22.10	23.75	26.52	27.61	28.58	29.49	30.54	30.14	28.51	28.63
8.75	30.24	30.68	28.98	27.18	26.12	25.17	25.21	12.44	22.38	23.89	27.34	27.91	28.65	29.38	30.68	30.24	28.67	28.87
11.70	35.27	36.74	35.27	33.37	31.42	30.64	26.83	20.10	27.98	28.62	31.19	32.44	33.09	33.72	36.74	35.27	34.35	33.91
11.80	35.51	36.65	35.12	33.56	31.59	31.36	27.38	18.32	27.45	28.80	31.12	32.67	33.47	34.24	36.65	35.51	34.44	34.02
12.55	37.22	38.55	37.02	34.49	33.18	32.12	29.52	19.00	28.32	29.91	32.80	34.37	35.72	36.99	38.55	37.22	36.00	35.85
14.70	39.83	41.78	40.44	37.70	36.62	34.18	42.55	22.00	30.78	32.09	34.91	36.36	37.67	38.91	41.78	39.83	39.83	38.28
15.00	41.19	42.23	40.76	38.06	37.39	35.33	32.12	22.15	31.69	33.09	36.22	36.99	38.53	39.97	42.23	41.19	39.77	39.28
16.20	41.78	43.46	42.15	40.55	38.53	36.79	30.71	23.93	33.90	35.60	37.75	38.82	40.16	41.45	43.46	41.78	41.00	40.86
15.65	40.69	43.16	42.38	40.16	38.50	36.24	30.92	21.96	33.78	35.30	38.00	38.85	40.57	42.20	43.16	40.69	40.67	40.71
15.35	40.51	42.92	41.65	39.47	38.93	35.98	41.90	22.34	32.77	34.27	37.33	38.82	40.39	41.90	42.92	40.51	41.17	40.31
15.71	41.01	43.38	42.13	40.08	37.58	35.36	29.45	21.45	33.31	35.84	38.69	39.26	40.91	42.48	43.38	41.01	40.36	41.05
16.30	41.28	44.53	42.97	40.00	38.74	36.59	29.09	20.72	32.61	35.63	39.18	40.63	42.28	43.84	44.53	41.28	40.98	41.75
16.40	40.82	44.30	42.94	40.31	38.77	36.45	29.52	20.95	33.28	35.98	40.03	41.40	42.92	44.39	44.30	40.82	40.94	42.09

Impeller Area Ratio   ?.25
Nozzle Exit Diam   1?.25 in
Inlet Entrance Length   33. in

mph	rpm	Ts lb	Qs ft-lb	Trim deg	Duct Pressure Fwd psi	Aft psi	Q ft³/sec	Vj ft/sec	TJ lb	Hp ft	SHP hp	Np	Jc
3.85	620	176	42.3	0.7	.0	-.62	11.23	13.74	175	2.59	5.0	0.66	0.85
5.00	882	436	92.0	-2.4	-.11	-1.22	15.49	18.95	347	6.43	15.4	0.73	0.82
5.20	910	390	86.6	-1.8	-.62	-1.29	16.47	20.15	399	5.75	15.0	0.72	0.85
7.20	1186	553	130.4	4.8	-.07	-2.34	22.09	27.00	704	8.15	29.4	0.70	0.87
7.50	1185	572	131.6	5.5	-.03	-2.39	22.04	26.96	679	8.43	29.7	0.71	0.87
11.20	1588	1149	271.4	7.5	.07	-3.34	31.02	37.92	1293	16.94	82.1	0.73	0.92
11.25	1591	1177	270.5	7.9	.13	-3.35	31.05	37.96	1293	17.35	81.9	0.75	0.91
12.85	1696	1353	302.6	7.9	.22	-3.77	33.00	40.34	1376	19.95	97.7	0.76	0.91
21.10	1899	1410	327.8	4.5	.20	-3.12	37.83	46.25	1123	20.79	118.5	0.75	0.93
22.32	1943	1370	334.1	5.5	.22	-2.87	39.19	47.91	1154	20.20	123.6	0.73	0.95
24.90	2138	1759	420.0	4.2	.20	-3.71	43.24	52.86	1371	25.93	171.0	0.74	0.95
27.55	2396	1955	498.2	8.3	-1.30	-4.24	48.58	59.39	1789	28.82	227.3	0.70	0.95

Impeller Area Ratio: 2.05
Nozzle Exit Diam: 12.35 in
Inlet Entrance Length: 33. in

mph	Port Side Velocities, ft/sec							0.5R	Starboard Side Velocities, ft/sec								Q, ft³/sec	
	6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Stbd
3.85	-	11.79	14.44	14.22	14.51	14.36	14.36	11.83	13.14	12.73	13.69	14.65	14.14	13.84	6.81	-	11.67	10.79
5.00	-	20.88	22.90	20.42	20.77	19.41	4.59	0.?	2.05	16.48	20.00	21.08	21.52	22.38	12.27	-	16.36	14.61
5.20	-	17.59	21.42	20.93	21.47	21.28	21.13	16.89	17.17	17.47	20.26	21.86	21.18	20.47	9.84	-	17.27	15.67
7.20	-	23.49	29.16	27.64	28.32	28.10	28.58	21.32	25.01	23.58	28.47	28.17	27.96	27.76	13.22	-	23.03	21.16
7.50	-	24.37	29.20	27.22	28.43	28.14	28.43	20.44	25.13	23.49	28.47	28.36	27.98	27.61	12.05	-	23.08	20.99
11.20	-	38.61	43.65	38.99	37.33	35.81	15.08	6.49?	19.30?	32.41	36.48	38.00	39.31	40.57	12.98?	-	31.02	?
11.25	-	38.44	43.65	39.15	37.84	35.98	14.07?	6.65?	19.19?	32.41	36.30	38.09	39.31	40.50	12.69?	-	31.05	?
12.85	-	40.11	45.70	42.20	40.47	38.69	15.22	4.47?	20.16?	34.52	38.96	40.29	41.78	43.27	0.?	-	33.00	?
21.10	-	44.34	48.84	46.84	46.23	44.06	34.03	12.69	35.24	40.37	44.58	44.70	46.25	47.73	0.?	-	37.83	?
22.30	-	45.07	49.93	48.12	48.17	46.11	38.22	17.14	36.33	41.40	45.10	45.72	47.35	48.90	0.?	-	39.19	?
24.90	-	49.38	55.55	53.33	52.15	51.01	42.94	16.22	38.74	44.96	49.16	50.41	52.31	54.35	0.?	-	43.24	?
27.55	-	54.85	63.20	59.56	59.75	57.22	46.11	13.38	36.10	48.84	54.94	54.75	57.91	60.91	0.?	-	48.58	?

Impeller Area Ratio   .25
Exit Diam   10.5 in
Inlet Entrance Length   33. in

mph	rpm	Ts lb	Qs ft-lb	Trim deg	Duct Pressure Fwd psi	Aft psi	Q ft³/sec	Vj ft/sec	TJ lb	Hp ft	SHP hp	Np	Jc
3.65	588	222	53.4	1.1	.01	-.37	9.18	15.20	174	3.27	6.0	0.57	0.73
4.95	797	618	118.2	-1.1	-.01	-.24	13.20	21.87	372	9.11	17.9	0.76	0.78
5.60	812	420	79.5	5.2	.07	-.56	12.58	20.82	307	6.19	12.3	0.72	0.73
5.30	879	507	97.7	0.3	.00	-.72	?	?	?	7.47	16.3	?	?
6.75	1132	795	167.5	5.3	.05	-1.26	17.50	28.98	644	11.72	36.1	0.64	0.73
6.95	1136	800	167.4	5.7	.03	-1.28	17.38	28.78	623	11.79	36.2	0.64	0.72
7.45	1237	1042	216.0	4.5	.00	-1.13	18.39	30.46	694	15.36	50.9	0.63	0.70
8.95	1388	1786	354.8	6.2	.07	-.51	?	?	?	26.33	93.8	?	?
9.50	1464	1987	395.4	7.3	.06	-.63	?	?	?	29.29	110.2	?	?
20.60	1653	2290	466.0	6.6	-1.28	.13	?	?	?	33.76	146.7	?	?
22.60	1667	2312	466.6	6.0	-1.09	-.52	?	?	?	34.09	148.1	?	?
26.65	1842	2562	547.1	5.6	-2.33	.78	?	?	?	37.77	191.9	?	?
27.45	1847	2669	553.9	4.5	-1.80	.74	?	?	?	39.35	194.8	?	?
27.60	1851	2659	555.7	4.0	-1.91	.88	?	?	?	39.20	195.8	?	?

Impeller Area Ratio: ...
Nozzle Exit Diam: 10.5 in
Inlet Entrance Length: 33. in

mph	Port Side Velocities, ft/sec							Starboard Side Velocities, ft/sec									U, ft/sec	
	6.5R	6.0R	5.5R	4.5R	3.5R	2.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R	Port	Stbd
3.65	-	-	-	15.49	18.35	17.04	18.35	16.09	16.42	14.80	17.71	16.29	11.52	-	-	-	9.02	9.33
4.95	-	-	-	23.22	25.79	25.83	24.79	17.66	23.17	24.24	24.58	22.71	16.22	-	-	-	13.09	13.31
5.60	-	-	-	23.71	25.09	23.12	21.91	18.86	20.00	20.88	24.54	21.86	15.56	-	-	-	12.58	12.57
5.30	-	-	-	23.49	25.59	3.24	0.?	0.?	0.?	20.21	24.41	21.08	14.94	-	-	-	?	?
6.75	-	-	-	31.15	34.09	33.37	28.36	16.76	30.92	31.72	34.88	31.05	22.00	-	-	-	17.00	18.00
6.95	-	-	-	30.71	34.09	32.93	28.87	17.23	30.40	31.85	34.37	30.81	21.76	-	-	-	16.90	17.86
7.45	-	-	-	35.95	38.38	36.62	12.31?	0.?	25.79	34.40	38.55	35.03	24.79	-	-	-	17.78	19.00
8.95	-	-	-	44.34	40.70	2.51	0.?	0.?	0.?	0.?	40.18	38.39	27.14	-	-	-	?	?
9.50	-	-	-	46.57	41.32	0.?	0.?	0.?	0.?	0.?	42.30	40.91	29.02	-	-	-	?	?
20.60	-	-	-	54.98	52.86	16.29	0.?	0.?	0.?	24.41?	49.99	45.86	32.44	-	-	-	?	?
22.60	-	-	-	55.82	54.93	26.44	0.?	0.?	0.?	35.39	50.78	47.20	33.40	-	-	-	?	?
26.66	-	-	-	60.96	58.94	25.75	0.?	0.?	0.?	44.82	56.96	52.92	37.42	-	-	-	?	?
27.45	-	-	-	60.54	59.91	31.36	0.?	0.?	0.?	49.33	57.60	54.13	38.39	-	-	-	?	?
27.60	-	-	-	60.30	60.25	31.22	0.?	0.?	0.?	47.82	57.23	53.98	38.39	-	-	-	?	?

Impeller Area Ratio 1.0
Inlet Entrance Length 33. in

Bollard Pull Test, 10.5-in Nozzle

rpm	Ts lb	Qs ft-lb	Duct Pressure Fwd psi	Aft psi	Pull lb	Q ft³/sec	Vj ft/sec	Tj lb	Hp ft	SHP hp	Np	Jc
612	346	66.2	- .08	- .31	200	7.42	12.35	178	5.10	7.71	0.56	0.57
900	770	145.2	- .15	- .54	350	?	?	?	11.35	24.9	?	?
1205	1420	268.8	- .25	- .90	650	?	?	?	20.94	61.7	?	?
1499	2174	420.3	- .36	-1.34	1000	14.93	24.84	719	32.05	120.0	0.45	0.47
1747	2707	539.9	- .45	-1.83	1250	17.10	28.45	944	39.91	179.6	0.43	0.46

Bollard Pull Test, 12.25-in Nozzle

rpm	Ts lb	Qs ft-lb	Duct Pressure Fwd psi	Aft psi	Pull lb	Q ft³/sec	Vj ft/sec	Tj lb	Hp ft	Shp hp	Np	Jc
622	219	47.5		- .65	200	11.14	13.62	294	3.23	5.6	0.73	0.84
911	499	102.0		-1.63	500	15.80	19.33	592	7.37	17.7	0.75	0.81
1197	896	181.0		-3.05	850	20.86	25.52	1028	13.23	41.2	0.76	0.82
1413	1308	277.1		-4.50	1400	25.43	31.12	1527	19.31	74.5	0.75	0.84
1863	1670	450.7		-6.90	2250	30.93	37.84	2259	24.66	159.9	0.54	0.78

Free-Running Test, 10.5-in Nozzle

mph	rpm	Ts lb	Qs ft-lb	Trim deg	Duct Pressure Fwd psi	Pull Aft psi	Q ft³/sec	Vj ft/sec	Tj lb	Hp ft	SHP hp	Np	Jc
4.20	625	298	54.5	0.9	.02	- .31	9.62	16.00	184	4.39	6.5	0.74	0.72
4.80	836	675	123.5	-1.2	.01	- .30	13.42	22.33	398	9.95	19.7	0.77	0.75
22.05	1516	1925	364.7	3.6	- .62	.45	24.55	40.66	394	28.38	105.3	0.75	0.76
13.80	1684	2405	495.8	7.5	.20	- .74	?	?	?	35.46	159.0	?	?
18.30	1931	2701	543.3	5.3	-1.06	- .51	24.57	40.68	656	39.82	199.7	0.56	0.60
23.30	1861	2758	553.1	4.5	- .89	- .16	23.75	39.33	235	40.66	196.0	0.56	0.60
24.35	1879	2712	545.3	6.3	.10	.71	25.33	41.95	306	39.98	195.1	0.59	0.63

34

Inlet Entrance Length: ??. ??

Bollard Pull Test, 10.5-in Nozzle

rpm		Port Side Velocities, ft/sec								Starboard Side Velocities, ft/sec									V, ft/sec	
	6.5R	6.0R	5.5R	4.5R	3.5R	~.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R		Port	Stbd
612	-	-	-	17.47	19.04	6.49	3.55	3.24	0.?	0.?	16.92	16.73	15.22	-	-	-		7.40	?
900	-	-	-	17.77	26.85	0?	2.05	0.?	0.?	0.?	23.08	23.12	22.00	-	-	-		?	?
1205	-	-	-	32.61	30.47	0?	2.90	0.?	0.?	0.?	30.02	31.05	29.74	-	-	-		?	?
1499	-	-	-	40.83	37.64	7.?	4.10	0.?	0.?	0.?	37.16	37.25	36.71	-	-	-		14.93	?
1774	-	-	-	45.42	41.27	11.96	7.95	0.?	0.?	0.?	40.42	40.96	39.74	-	-	-		17.10	?

Bollard Pull Test, 12.25-in Nozzle

rpm		Port Side Velocities, ft/sec								Starboard Side Velocities, ft/sec									V, ft/sec	
	6.5R	6.0R	5.5R	4.5R	3.5R	~.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R		Port	Stbd
622	-	12.98	15.83	14.14	14.28	13.06	4.59	0.?	6.49	12.90	14.73	15.08	14.87	14.58	11.70	-		11.17	11.12
911	-	20.88	24.45	21.03	20.62	12.31	1.45	0.?	5.23	17.77	20.98	22.00	21.72	21.37	17.86	-		15.72	15.86
1197	-	29.06	33.90	28.76	27.61	12.23	0.?	0.?	6.65	21.32	27.61	29.42	29.02	28.84	23.15	-		20.92	20.80
1413	-	36.74	42.43	35.78	34.06	12.73	0.?	0.?	5.03	25.71	34.18	36.04	36.48	36.94	24.13	-		25.83	25.03
1863	-	44.91	53.37	43.72	40.99	15.69	2.05	0.?	3.24	32.54	42.53	43.48	44.72	46.34	21.18	-		32.22	29.63

Free-Running Test, 10.5-in Nozzle

| rpm		Port Side Velocities, ft/sec								Starboard Side Velocities, ft/sec									V, ft/sec	
	6.5R	6.0R	5.5R	4.5R	3.5R	~.5R	1.5R	0.5R	1.5R	2.5R	3.5R	4.5R	5.0R	5.5R	6.0R	6.5R		Port	Stbd
625	-	-	-	16.67	18.86	18.92	18.45	6.49	16.80	15.08	18.64	17.59	14.51	-	-	-		9.42	9.82
836	-	-	-	23.58	26.83	26.91	23.80	8.21	21.52	22.00	26.79	23.22	20.52	-	-	-		13.22	13.62
1516	-	-	-	61.16	55.61	28.54	0.?	9.12	0.?	38.44	56.23	52.84	45.88	-	-	-		23.62	25.49
1684	-	-	-	53.76	51.73	7.40?	9.62	0.?	0.?	20.47	48.41	43.99	38.39	-	-	-		?	?
1931	-	-	-	59.77	57.58	24.54	11.05	2.71	28.43	29.63	54.00	49.25	43.53	-	-	-		24.00	25.13
1861	-	-	-	60.49	60.47	26.75	0.?	6.49	0.?	30.57	54.37	48.93	43.53	-	-	-		24.03	23.47
1879	-	-	-	59.77	57.58	26.36	11.24	9.00	5.80?	31.22	55.29	60.18	50.26	-	-	-		24.21	26.45
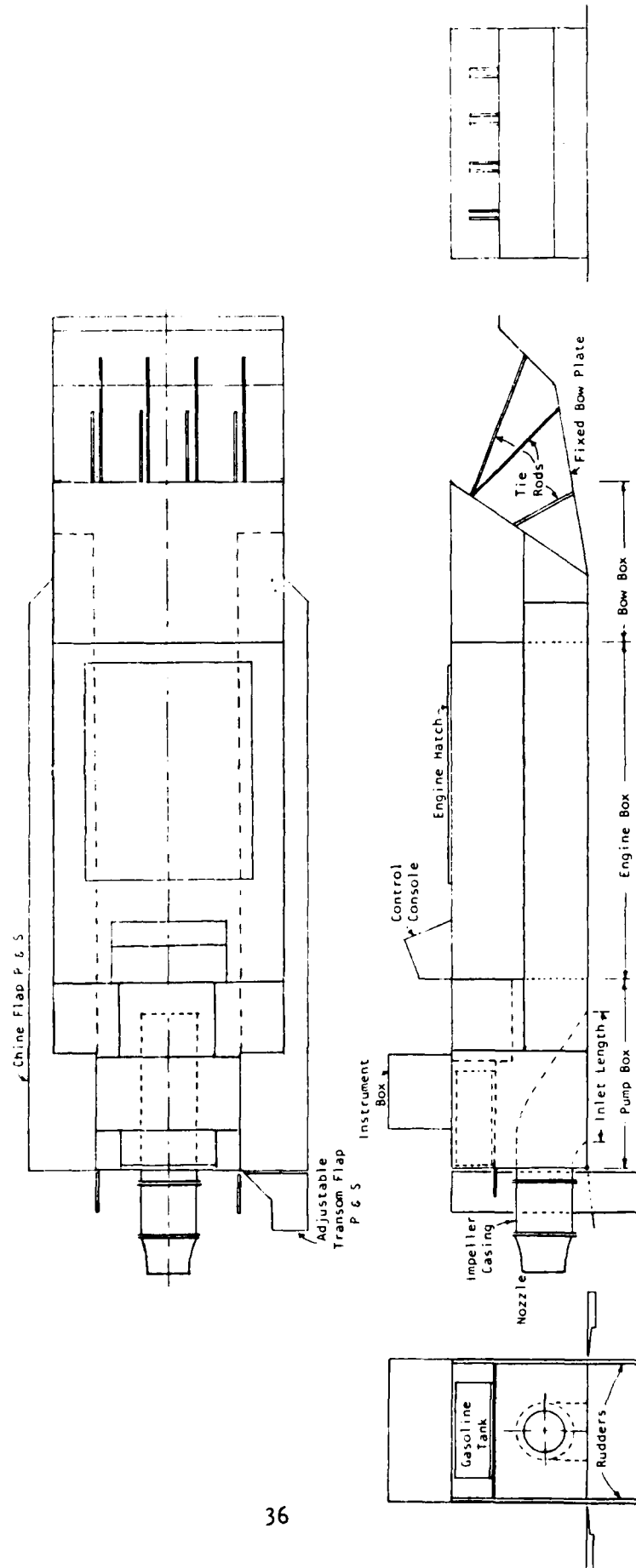
FIGURE 1 TESTCRAFT CONFIGURATION
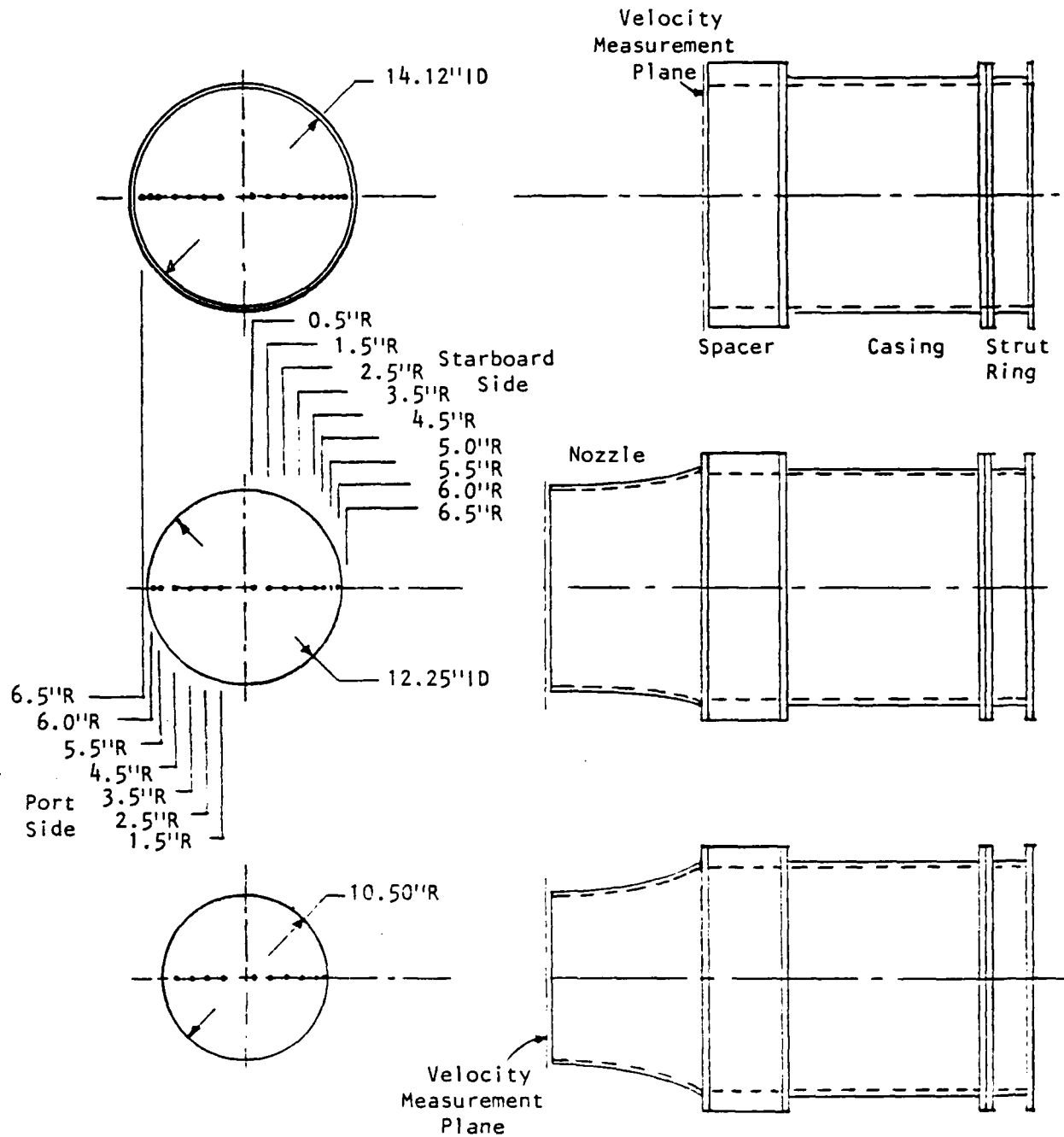
FIGURE 2   NOZZLE CONFIGURATIONS AND
VELOCITY MEASUREMENT GRID
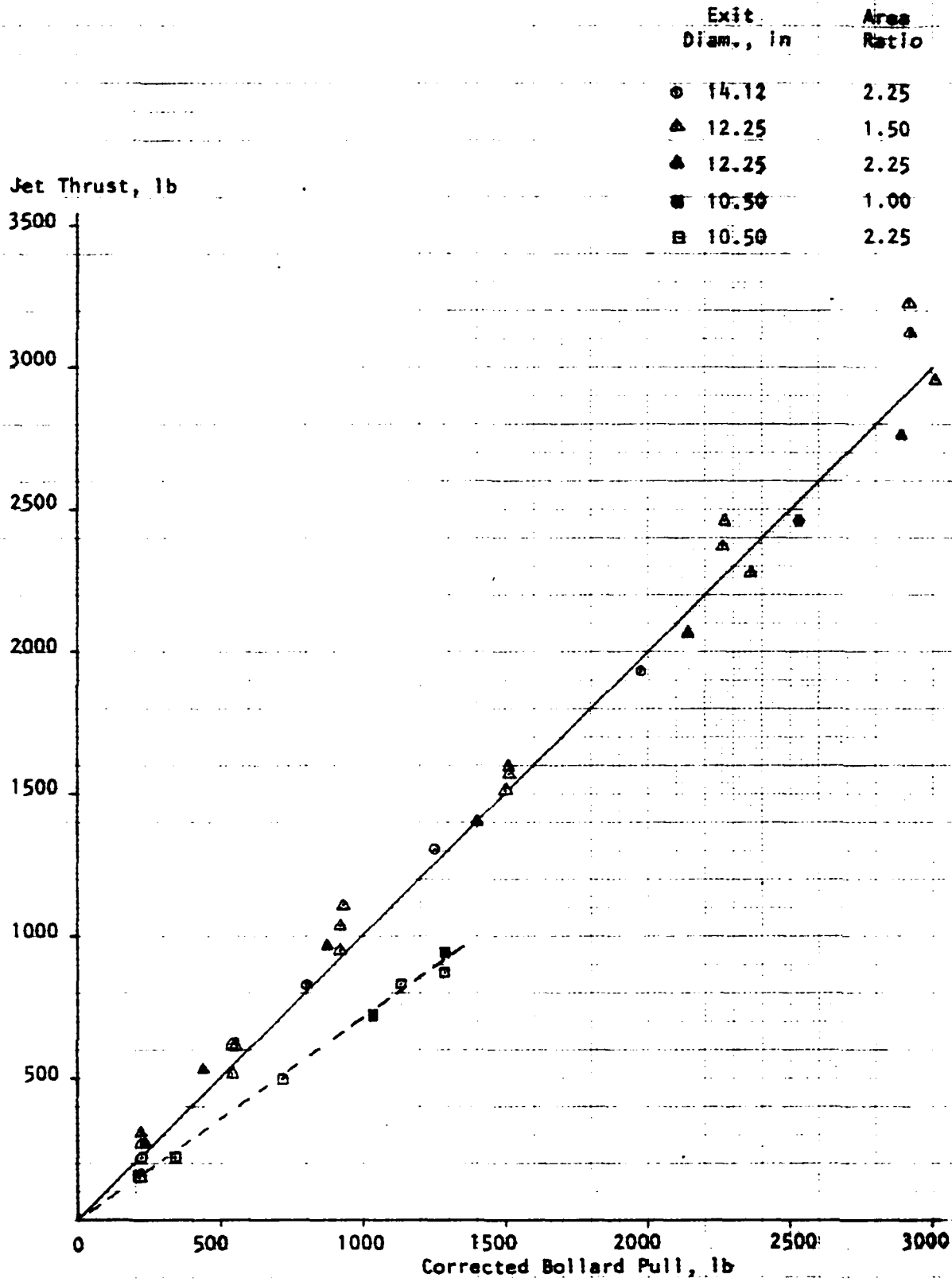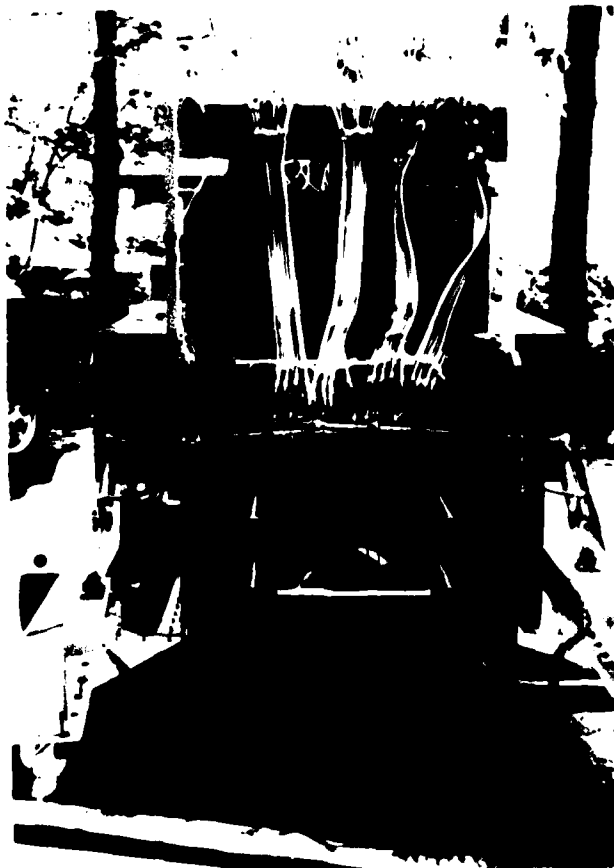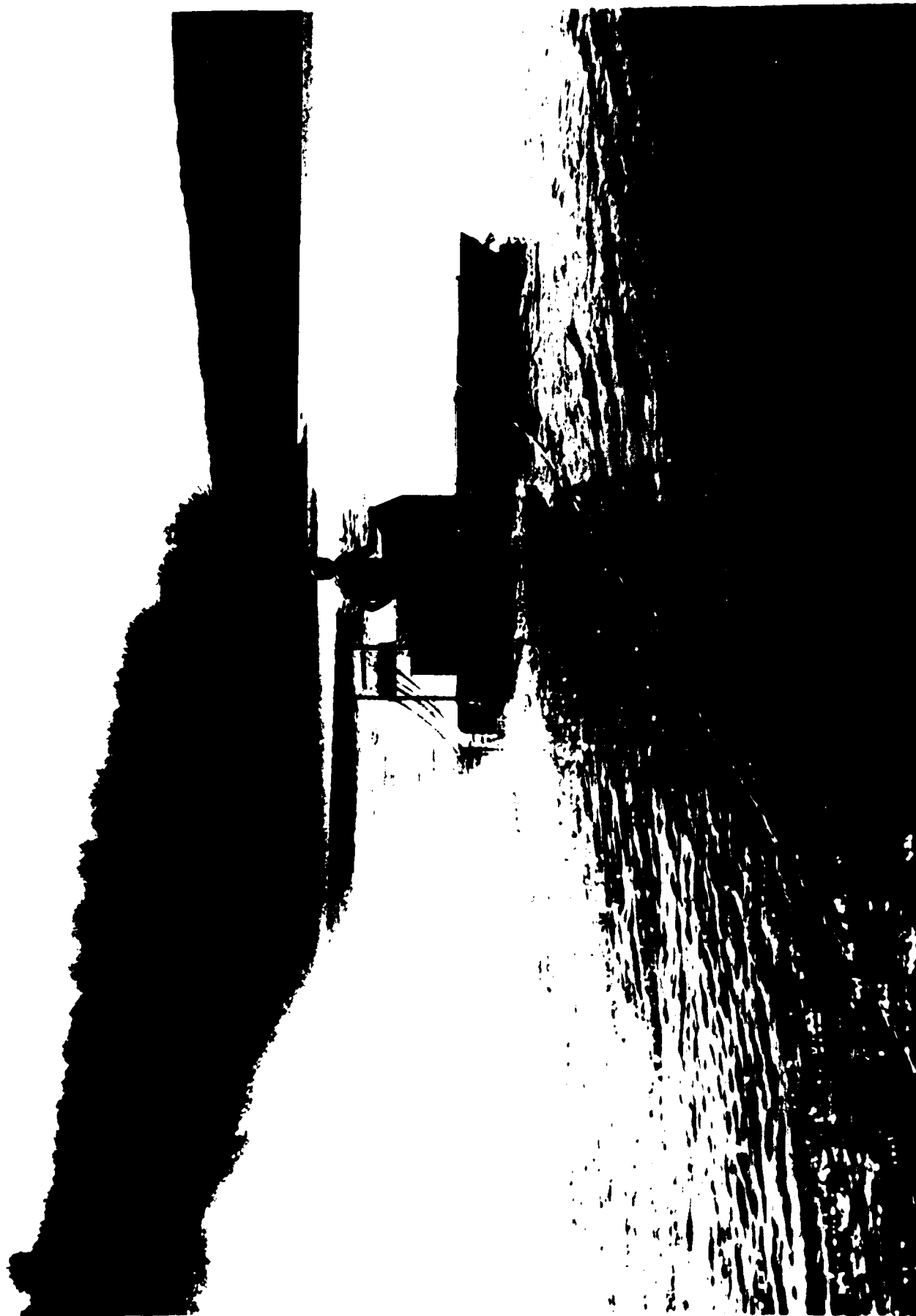
FIGURE 3 WATERJET THRUST VERSUS BOLLARD PULL

INSTRUMENTATION

BOLLARD PULL TEST

DISTRIBUTION LIST

(Contract N00014-83-C-0780)

<u>Copies</u>

7   David W. Taylor Naval Ship Research
                        And Development Center
                Bethesda, MD 20084

        5   S.S. Scharf, Code 1240
        1   J.G. Stricker, Code 2721
        1   Library, Code 522

1   Office of Naval Research
                800 N. Quincy
                Arlington, VA 22217
                Attn: Scientific Officer, Code 438

1   Office of Naval Research
                Resident Representative
                715 Broadway, 5th. Floor
                New York, New York 10003

1   Defense Technical Information Center
                Building 5, Cameron Station
                Alexandria, VA 22314

END

FILMED

5-85

DTIC